Electronic supplementary material

Biology Letters

Bridging the gap: parkour athletes provide new insights into locomotion energetics of arboreal apes

Lewis G Halsey[1], Samuel RL Coward[2,3], Susannah KS Thorpe[2]

[1]University of Roehampton, London, UK SW15 4JD

[2]University of Birmingham, Birmingham, UK B15 2TT

[3]Dudley College, Dudley, UK DY1 4AS

Detailed Materials and methods

The parkour athletes (traceurs) were recruited through the parkour companies *Parkour Generations* (London, UK) and *EMP* (Birmingham, UK). All participants were male. The study was undertaken in the Slater gymnasium at the University of Birmingham, U.K and at the Creation climbing centre in Moseley, U.K. Participants undertook some or all of four different activities: horizontal jumping, pole swaying, rope and ladder climbing. Each activity involved multiple conditions, which were designed to represent, within reason, the varying conditions experienced by great apes in the forest canopy. The jumping conditions were a short standing jump and a long standing jump. The swaying conditions were denoted by different pole stiffnesses to represent, within safety limits, a wide range of stiffnesses of trees that can be swayed sufficiently to bridge canopy gaps. A ladder simulates an ideal tree for climbing (evenly and conveniently spaced branches) while a rope represents the vines common in rainforests and often used by apes to gain height; their gripping feet facilitates the use of this vegetation for climbing.

During these activities, rate of oxygen consumption ($V'O_2$) was measured via a mobile respiratory gas analyser (Oxycon mobile, Viasys, Germany). At the end of each condition, participants were asked for their relative perceived exertion [RPE; 1, 2] towards the end of that period of activity. $V'O_2$ was converted to rate of energy expenditure i.e. power, in kJ, using a conversion of 20.1, assuming the metabolic substrate utilised was mainly carbohydrate [3].

Horizontal jumping

Participants jumped at set distances of either 1.8 or 1.2 m for around four minutes, at a frequency of one jump every 5 s (0.2 Hz) by jumping on the beep of an electronic metronome. They jumped

between springboards made firm by inserting a wooden chock between the top and bottom surfaces (stiffness = 881.3 N mm^{-1}, damping ratio = 0.13). Pilot tests confirmed that (1) the relationship between $V'O_2$ and jump rate is linear such that jump rate does not affect the calculated cost of oxygen consumption per jump, and (2) that $V'O_2$ is linearly related to jump distance.

Pole swaying

Three 5 m fibreglass poles of differing thicknesses (92, 79.2 and 68.5 mm diameter) and thus differing flexural stiffness (19 744, 30 375 and 39 488 Nm^2) were held vertically, one at a time, by attachment to a steel base plate of 5 m diameter, which was secured to a concrete floor. The poles were clamped within a 50 cm deep aluminium collar resulting in a free length of 4.5 m and horizontal stiffnesses at the tip of 1350, 1042 and 649 Nm^{-1}. This range overlaps with the stiffness of natural supports orang-utans have been observed to use for tree-sway in Sumatra [4, 5]. Each pole included foot supports at 3 m height along the free length of the pole, and rubber grip tape at the top end where participants tended to choose to hold the pole.

The participants climbed a ladder to scale the pole and stood on the foot supports. After a few sways to build momentum they then swayed the pole consistently to generate a steady amount of horizontal displacement for at least three minutes, using a method of their choosing. Up to three different conditions were recorded for each pole, represented by different amounts of displacement (low, medium and high). Amount of displacement was the choice of the participant, after discussions with the researchers to ensure that such displacement was significantly different to other conditions using the same pole and could be maintained for the required duration. Consistency of displacement over the duration of the condition was maintained where necessary by feedback from a researcher (SRLC) who was monitoring amount of displacement with the aid of markers placed on the wall behind the apparatus. Thus participants undertook up to nine pole sway conditions (i.e. up to three different amounts of displacement for three different poles). They were harnessed and attached to a belay throughout the activity and this was used to lower the participant to the ground after each condition. The order that participants undertook the conditions was randomised and they were able to practice in each condition before data collection started.

Rope and ladder climbing

Participants climbed up and down a 5 or 5.35 m rope, 36 mm in diameter, in a fashion of their own choosing. They repeated this without breaks as many times as possible (typically once but up to four times in certain instances). They did not touch the floor with their feet after starting to climb the rope until they had descended for the final time. Participants climbed a ladder set to be as vertical as possible (13 degrees), lashed to a girder at the top for safety, to the same height as the top of the rope. They then descended, repeating this cycle the same number of times as they had climbed and descended the rope. Thus for each participant, total vertical distance climbed was the same in the rope and the ladder conditions.

Protocols for measuring energy expenditure

For horizontal jumping and pole swaying, the participants were mainly metabolising aerobically, demonstrated by respiratory exchange ratios typically below 1, and RPE scores typically below 16 [6]. Either the last 30 s or, more typically, 60 s of data in each condition were used to calculate mean

$V'O_2$ during the activity, since at this time $V'O_2$ was confirmed to have plateaued indicating that the body had reached physiological steady state [7-9], normally after around 2 minutes as is typical for fit individuals [10-12]. $V'O_2$ was converted to rate of oxygen consumption per metre (mL O_2 m^{-1}) to represent energy expenditure. Such measures are considered to be an accurate representation of rate of energy expenditure during mainly aerobic activity.

During high intensity climbing, such as climbing a rope, a noteworthy proportion of metabolic expenditure is anaerobic, as indicated by considerable increases in blood lactate levels [13]. Thus for this activity, $V'O_2$ was recorded both during the activity and also during the entirety of the period afterwards during which excess post exercise oxygen consumption (EPOC) was exhibited. Furthermore, blood lactate levels were taken via finger prick blood samples before the activity and at 3, 5 and 7 minutes post activity to obtain a value approximating well to maximum blood lactate level reached [14-18]. Finally, participants were required to do a warm up on the rowing machine, this time for three minutes where for the first minute they undertook a stroke once every 5 s, for the second minute once every 4 s and for the final minute once every 3 s. To calculate rate of energy expenditure to rope climb, elevated oxygen consumption during the activity and oxygen consumption represented by the EPOC were calculated, along with an oxygen consumption equivalence of the maximum increase in lactate (mmol L^{-1}) in response to the exercise [maximum recorded increase multiplied by body weight, multiplied by 3 mL of O2; 19]. The period of EPOC was considered to be over when $V'O_2$ returned to below 500 ml O_2 min^{-1} [20]. Total energy expenditure to climb was calculated as the sum of these three elements [20]. For consistency, the same protocol was applied to the ladder climb.

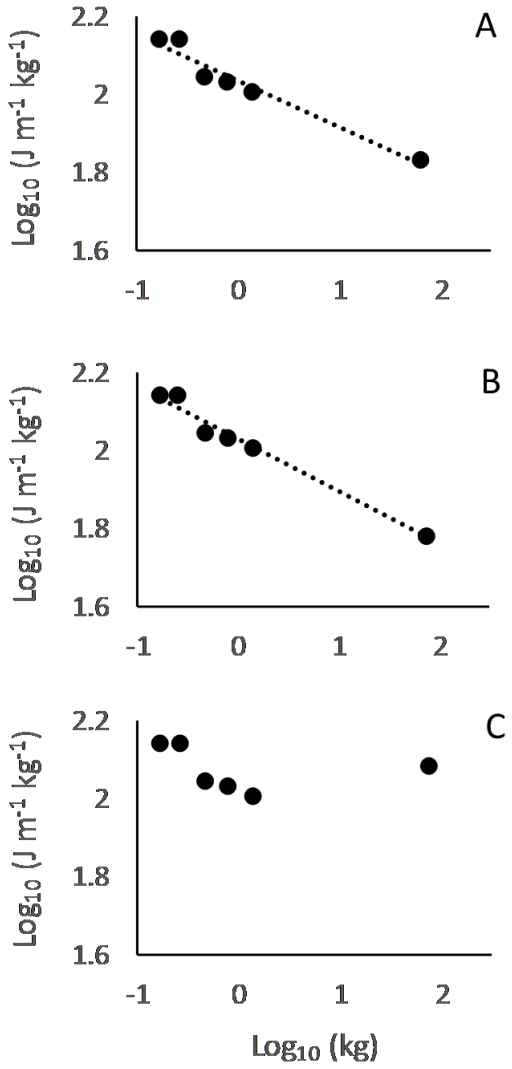
Film clips of the participants undertaking gap cross activities are available as supplementary materials. File names:

Swaying: ‘sway.mp4’

Rope climbing: ‘rope.mp4’

Details of re-analysis of dataset presented in Hanna et al. (2008)

Figure 1A in Hanna et al. [21] was digitised using Plot Digitizer 2.6.3. The data were graphed as a scatter plot in Excel on $\log_{10}$ axes. The linear relationship was negative (R^2 = 0.95; Supplementary Figure 1A). Climbing efficiency was calculated as defined in [21] as the net vertical mechanical work divided by the net metabolic cost. As would be expected mathematically, the $\log_{10}$ relationship between climbing efficiency and body mass was now positive and with exactly the same goodness of fit. Then, the data point in the dataset representing human climbing energy costs was replaced with a value calculated from the present dataset for climbing a ladder, and R^2 recalculated (0.97). Finally, the human data point was then replaced with that from the present dataset for climbing a rope (R^2 = 0.07).



Supplementary Figure 1. Log_{10} relationships between mass-specific energy costs to climb per unit distance and body mass, across primate species. A: data presented in Hannah et al. (2008) [21]; B: same data as present in (A) except that the data point for the energy cost of human vertical climbing (far right value) has been replaced with the value in the present study for climbing a ladder; C: the data point for the cost for human climbing is now represented by the value in the present study for

climbing a rope. For all three panels, note that the y axis does not reach zero; it ranges between 1.6 and 2.2.

1. Borg G. 1970 Perceived exertion as an indicator of somatic stress. *Scandinavian journal of rehabilitation medicine* **2**, 92-98.
2. Chen M., Fan X., Moe S. 2002 Criterion-related validity of the Borg ratings of perceived exertion scale in healthy individuals: a meta-analysis. *Journal of Sports Sciences* **20**, 873-899. (doi:10.1080/026404102320761787).
3. Schmidt-Nielsen K. 1997 Energy metabolism. In *Animal Physiology* (ed. Schmidt-Nielsen K.), pp. 169-214, 5th ed. Cambridge, Cambridge University Press.
4. Thorpe S.K.S., Crompton R.H., Alexander R.M. 2007 Orangutans use compliant branches to lower the cost of locomotion. *Biol Lett* **3**, 253-256.
5. van Casteren A., Sellers W.I., Thorpe S.K.S., Coward S., Crompton R.H., Ennos A.R. 2013 Factors Affecting the Compliance and Sway Properties of Tree Branches Used by the Sumatran Orangutan (*Pongo abelii*). *PLoS ONE* **8**(7), e67877. (doi:10.1371/journal.pone.0067877).
6. Scherr J., Wolfarth B., Christle J., Pressler A., Wagenpfeil S., Halle M. 2012 Associations between Borg's rating of perceived exertion and physiological measures of exercise intensity. *Eur J Appl Physiol* **Online**. (doi:0.1007/s00421-012-2421-x).
7. Meijer G.A., Westerterp K.R., Koper H., Hoor F.T. 1989 Assessment of energy expenditure by recording heart rate and body acceleration. *Med Sci Sports Ex* **21**(3), 343-347.
8. Terrier P., Aminian K., Schutz Y. 2001 Can accelerometry accurately predict the energy cost of uphill/downhill walking? *Ergonomics* **44**(1), 48-62.
9. Achten J., Gleeson M., Jeukendrup A. 2002 Determination of the exercise intensity that elicits maximal fat oxidation. *Med Sci Sports Ex* **34**(1), 92-97.
10. Chilibeck P.D., Paterson D.H., Petrella R.J., Cunningham D.A. 1996 The Influence of Age and Cardiorespiratory Fitness on Kinetics of Oxygen Uptake. *Canadian Journal of Applied Physiology* **21**(3), 185-196. (doi:10.1139/h96-015).
11. Whipp B., Wasserman W. 1972 Oxygen uptake kinetics for various intensities of constant-load work. *J Appl Physiol* **33**(3), 351-356.
12. ACSM. 2013 *American College of Sports Medicine's guidelines for exercise testing and prescription*, Lippincott Williams & Wilkins.
13. Booth J., Marino F., Hill C., Gwinn T. 1999 Energy cost of sport rock climbing in elite performers. *Brit J Sports Med* **33**, 14-18.
14. Astrand P., Hultman E., Danfelt J., Renolds G. 1986 Disposal of lactate during and after serious exercise in humans. *J Appl Physiol* **61**, 338-343.
15. Baltzopoulos V., Eston R., McLaren D. 1988 A comparison of power outputs on the Wingate test and on a test using an isokinetic device. *Ergonomics* **31**, 1693-1699.
16. Bedu M., Fellmann N., Spielvogel H., Falgariette G., Van Paraagh E., Coudert J. 1991 Force-velocity and 30s Wingate test in boys at high and low altitudes. *J Appl Physiol* **70**, 1031-1037.
17. Dodd S., Powers S., Callender T., Brooks E. 1984 Blood lactate disappearance at various intensities of recovery exercise. *J Appl Physiol* **57**, 1462-1465.
18. Frose E., Houston M. 1987 Performance during the Wingate anaerobic test and muscle morphology in males and female. *Int J Sports Med* **8**, 35-39.
19. di Prampero P., Ferretti G. 1999 The energetics of anaerobic muscle metabolism: a reappraisal of older and recent concepts. *Resp Physiol* **118**, 103-115.
20. Scott C., Leary M., TenBraak A. 2011 Energy expenditure characteristics of weight lifting: 2 sets to fatigue. *Applied Physiology, Nutrition and metabolism* **36**, 115-120.
21. Hanna J.B., Schmitt D., Griffin T.M. 2008 The energetics cost of climbing in primates. *Science* **320**, 320.